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CHARACTERIZATION TECHNIQUES FOR HIGH QUALITY ICF TARGETS

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CHARACTERIZATION TECHNIQUES FOR HIGH QUALITY ICF TARGETS*

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Abstract

To avoid the effects of fluid instabilities, stringent requirements must be imposed on the surface quality and wall thickness uniformity of fuel pellets used in Inertial Confinement Fusion compression experiments. We have developed a systematic method for specifying the type of defects which must be avoided and for evaluating measurement techniques for their suitability for detecting these defects. We review the techniques currently available and those under development to show the relationship between these capabilities and the current and future requirements for pellet uniformity. We also discuss the speed of these techniques and the implications for automated production of fuel pellets for a reactor.

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To obtain fusion targets which have the required symmetry and surface quality for inertial confinement fusion, it is necessary to develop adequate target measurement techniques. These techniques are necessary both to provide feedback during development of the fabrication procedures, and to inspect the final product. In this paper we outline the resolution and speed which must be met and review the capabilities of techniques currently in use and under active development. We also suggest some possibilities for future research and implications for power plant production processes.

Consider a simple target (Fig. 1) consisting of an inner fuel region surrounded by a hollow shell of high density "pusher" and an outer layer of "ablator". If one part of the pusher or ablator wall is initially thicker than the other, then as the pellet is imploded, the thick side will lag behind the other and the implosion will not converge symmetrically. Also, the imploding pellet is subject to fluid instabilities. Small perturbations on the surface grow exponentially in amplitude as the pellet is compressed and can cause breakup of the imploding shell.

The growth rate of the perturbation is dependent on its initial lateral dimensions or "wavelength." From computational analysis of fusion implosions, one can generate a plot of the maximum allowable initial amplitude for a perturbation as a function of perturbation wavelength. Figure 2 shows such curves for two different target sizes. The smaller size is appropriate for current lasers (10 kJ), while the larger target would be appropriate for more powerful lasers (100 kJ). While the actual allowable defect amplitudes depend on the specifics of the pellet construction and the implosion process, the general shape of the curve will apply to all targets of roughly the same size.

Curves such as those shown in Fig. 2 are very useful in deciding which characterization techniques should be pursued for fusion targets. Generally when one considers the "resolution" of a measurement technique, one thinks only of the spatial resolution. In evaluating techniques for fusion targets, however, a more important parameter is the sensitivity of the technique for defects with a very low amplitude and a relatively long wavelength. The basic task in characterizing fusion targets is to develop a set of techniques with a combination of spatial and amplitude resolution which covers the entire "defect space" shown in Fig. 2.

Currently the three primary techniques for measuring the uniformity of inertial fusion targets are optical interference microscopy, microradiography, and scanning electron microscopy. Figure 3 shows the approximate resolution limits which can be achieved with these three measurement techniques if they are fully developed. With the combined coverage of all three techniques, most of the relevant defects can be detected. Other techniques which can be used to supplement the above methods are acoustic microscopy, mechanical stylus measurements, air balancing, and destructive sectioning.

In addition to the resolution requirements, the techniques should be nondestructive and must be fast enough to allow complete characterization of a target sphere in an acceptable length of time. The speed constraint becomes particularly important when the techniques are used for sorting pellets as well as for final measurements.

We have underway a program to develop all of the above techniques to the maximum achieveable resolution and to automate the measurement procedures in order to provide the necessary speed. The first fully automated system for mapping a sphere with transmission interferometry was completed recently. A schematic of the system is shown in Fig. 4. This system employs computer control of both the manipulation and the phase measurement to map the wall thickness variations of a target microsphere. The data is stored on a flexible disc cartridge and can be displayed immediately or saved for later analysis. The entire time to map a 200 μm diameter sphere with 2 μm spatial resolution and 10 nm thickness resolution is less than one minute. We have also completed an automated scanning electron microscope and automation of radiographic measurements is under intensive development.

An important future issue is what type of characterization techniques might be incorporated into a power plant. It has been our experience that most types of defects, once they have been identified, can be eliminated by careful control of the production process. Some defects are more difficult to control than others, however, and it may be that for some fabrication processes, elimination of specific types of defects may be too difficult or expensive.

Our general approach is twofold: For the near term, while inertial fusion is in an experimental stage, we are pursuing measurement techniques which are capable of locating and measuring all possible defects but which are not fast enough to be used for sorting large numbers of targets. For the long term, we plan to determine which types of defects cannot be eliminated by fabrication process control and then build highly specialized, rapid sorting systems which do not detect all possible defects but which can discriminate against pellets with a specific type of defect. Such systems could be fast enough and inexpensive enough to be included in the target production sequence for a reactor.

Figure Captions

FIGURE 1. Basic structure of an inertial fusion target. To obtain high density compression of the fuel, the pusher and ablator layers must be extremely uniform.

FIGURE 2. Pellet wall uniformity requirements. Curve (a) is for a target approximately 200 μm in diameter with a 20 μm thick wall. Curve (b) is for one 600 μm in diameter and 50 μm thick. The smaller size pellet is appropriate for current 10 kJ lasers, while the larger pellet would be appropriate for a 100 kJ laser.

FIGURE 3. Resolution limits attainable with three common target measurement techniques. The horizontal hatching indicates a surface contour measurement while the vertical hatching indicates a wall thickness measurement. Ideally, one should be able to make both measurements over the entire defect space which is of interest.

FIGURE 4. Block diagram of TOPO-II, an automated interferometric mapping system currently used to measure fusion pellets. This is one of several automated characterization techniques being developed at Lawrence Livermore Laboratory.

TYPICAL ICF TARGET STRUCTURE

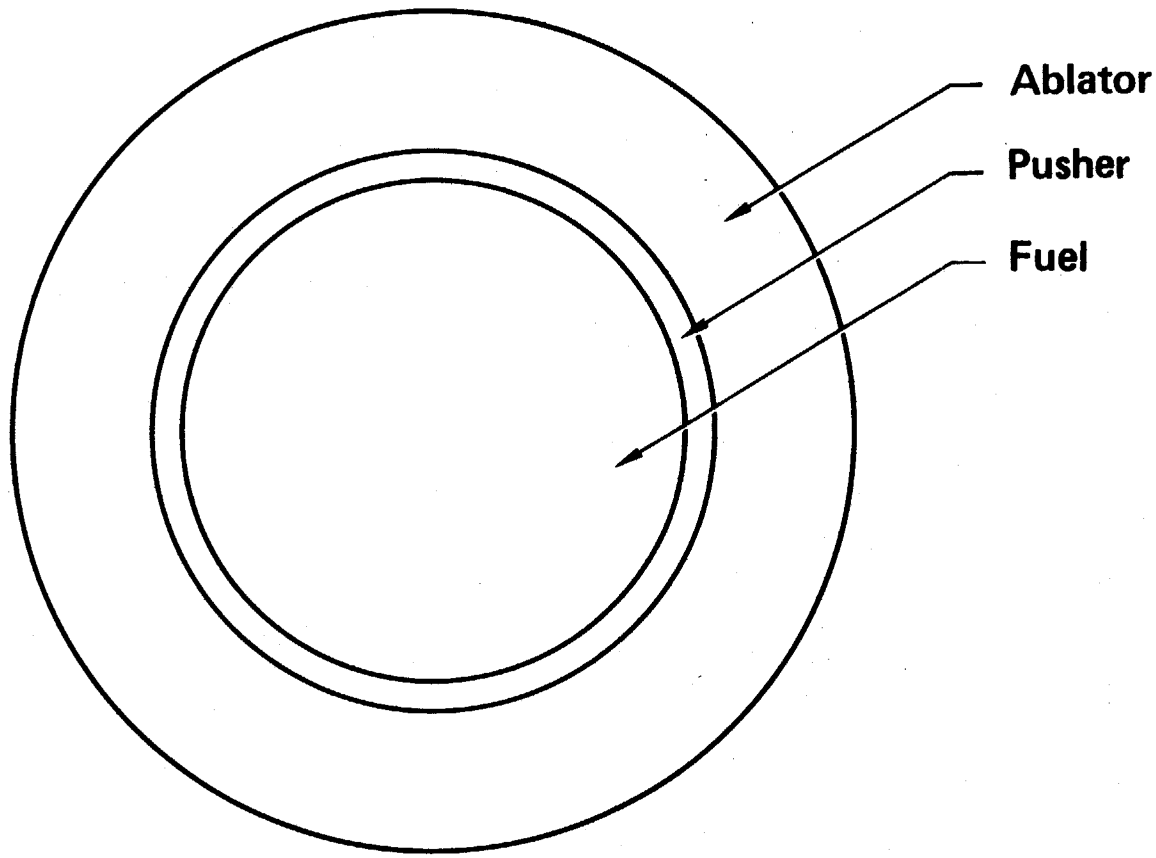

Figure 1

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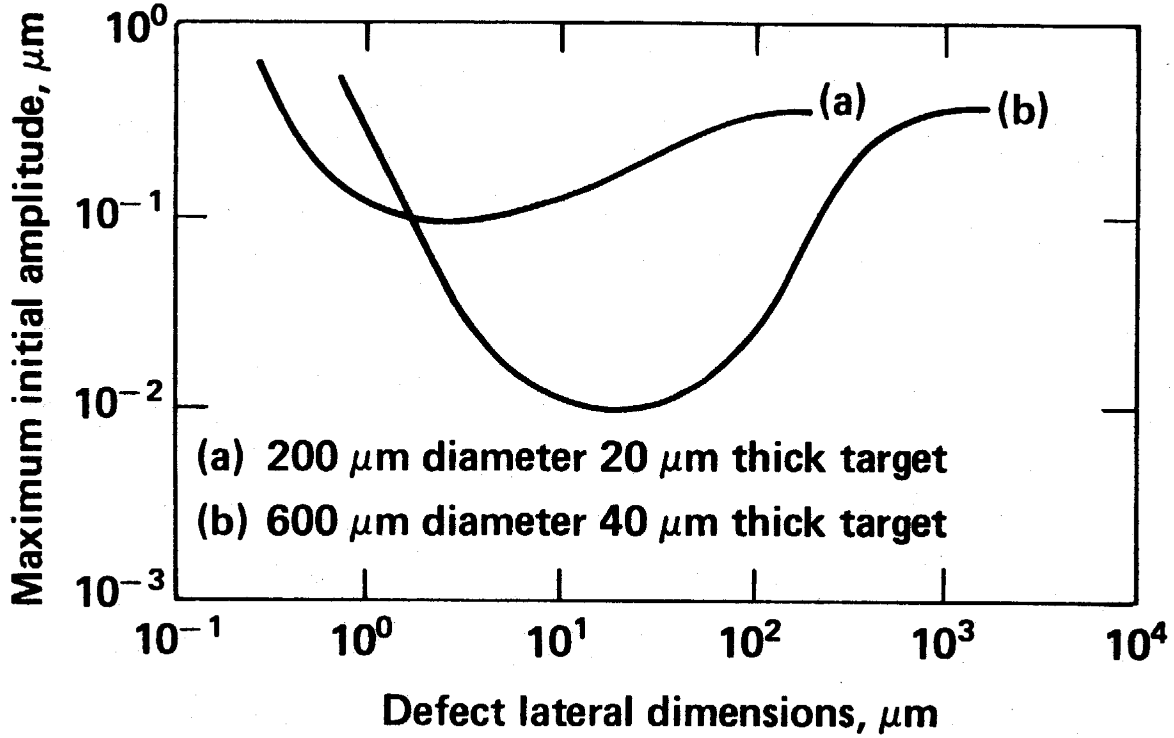
Maximum initial amplitude, μm
10^0
10^−1
10^−2
10^−3
10^−1
10^0
10^1
10^2
10^3
10^4
Defect lateral dimensions, μm
(a)
(b)
(a) 200 μm diameter 20 μm thick target
(b) 600 μm diameter 40 μm thick target

Figure 2

CHARACTERIZATION CAPABILITIES vs REQUIREMENTS FOR HIGH GAIN TARGETS (opaque)

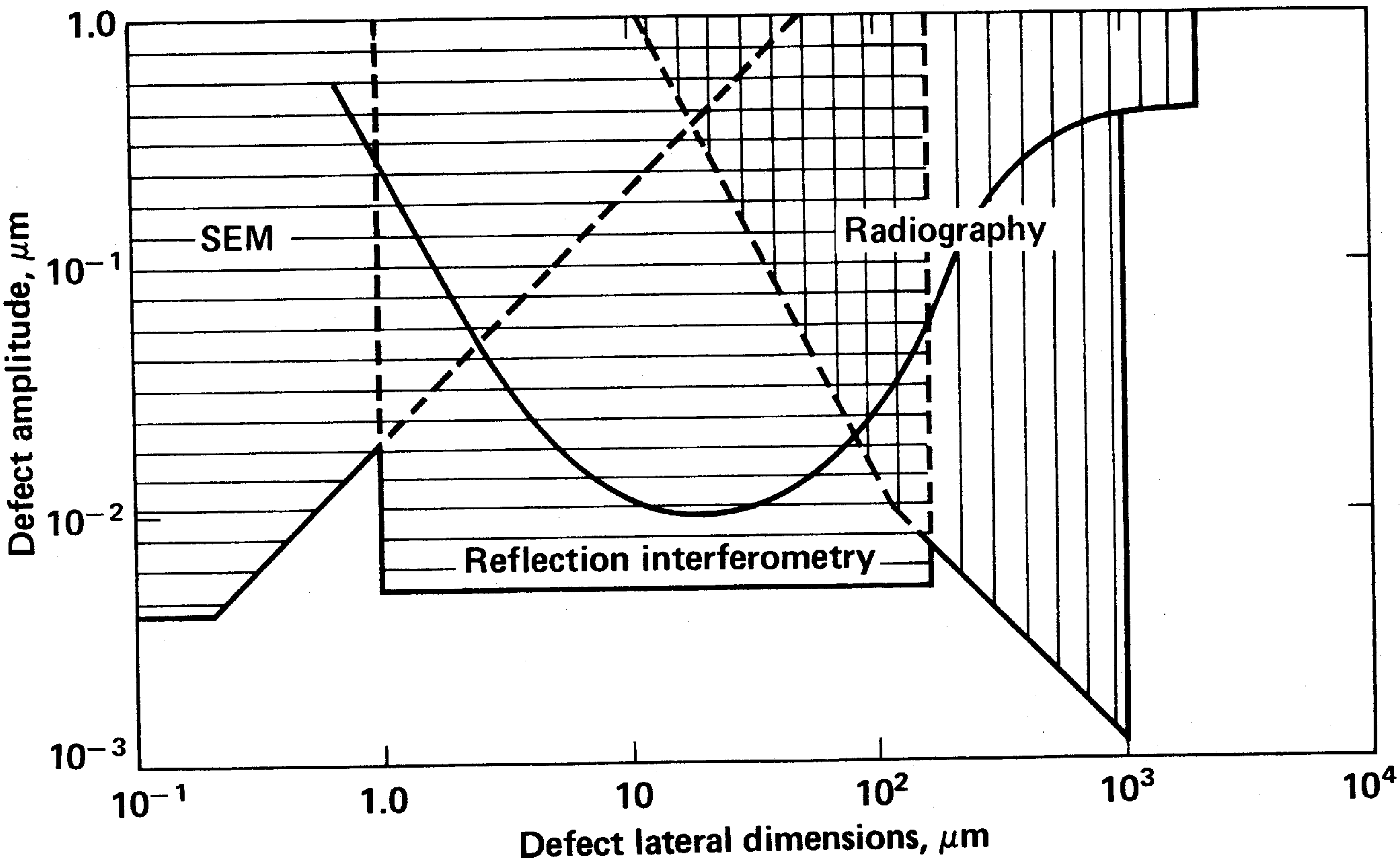

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Figure 3

TOPO II AUTOMATED INTERFEROMETRIC SPHERE MAPPING SYSTEM

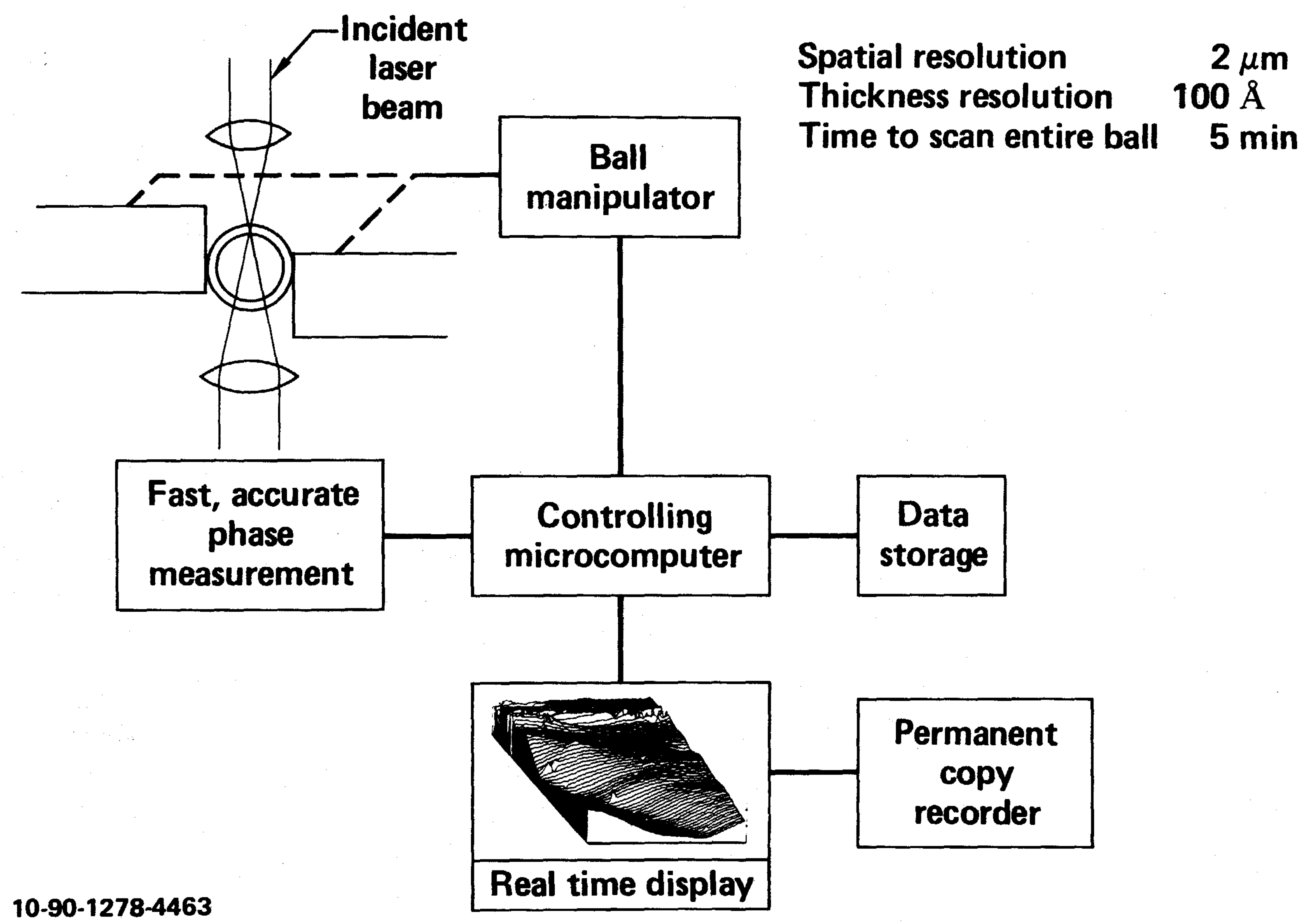

Figure 4